Evaluating the Economic Effectiveness of Pathogen Reduction Technologies in Cattle Slaughter Plants

Scott A. Malcolm
Food and Resource Economics, 213 Townsend, University of Delaware, Newark, DE 19717. E-mail: malcolm@udel.edu

Clare A. Narrod
Office of Risk Assessment and Cost Benefit Analysis/USDA, Room 5248 South Building - Stop 3811, 1400 Independence Avenue, S.W., Washington, DC 20250–3811. E-mail: cnarrod@oce.usda.gov.

Tanya Roberts
Economic Research Service/USDA, 1800 M Street NW - 4081N, Washington, DC 20036–5831. E-mail: tanyar@ers.usda.gov.

Michael Ollinger
Economic Research Service/USDA, 1800 M Street NW - 4097N, Washington, DC 20036–5831. E-mail: ollinger@ers.usda.gov

ABSTRACT

Increasing risk and costs from food-borne illness has led food-processing firms to intensify pathogen reduction efforts. Hazard Analysis and Critical Control Points (HACCP) is one system for evaluating which hazards need to be controlled and where in the production process they can be controlled. Firms may choose among many competing technologies that differ in cost and effectiveness at controlling pathogen growth. To evaluate a firm's pathogen control options, a probabilistic risk analysis model based on typical slaughterhouse practices is linked to a decision model to evaluate the cost effectiveness of seven combinations of pathogen-reducing technologies. The likely comparative advantage of different strategies for large vs. small slaughterhouses is examined. Risk is compared for two cases with the same mean risk to illustrate the importance of correct model specification. The report concludes with a discussion of the institutional barriers and incomplete markets that affect the adoption and development of more effective pathogen reduction technologies. [EconLit citations: Q180, O300, L510]. © 2004 Wiley Periodicals, Inc.

1. INTRODUCTION

Globalization of the food supply has increased the risk of spreading food-borne illness across international boundaries.[1] In part, this has caused food safety issues to rise to the forefront of global trade agendas. Concerns over food safety have become increasingly

---

[1]Today, Japan commonly accepts shipments of fresh meat from the United States, Australia, and New Zealand. Notable are the market access problems United Kingdom beef faced after its association with BSE.

important in the establishment of non-tariff trade barriers. Consequently, risk assessment and economic analysis have become linked. Typically, these activities have been carried out independently as universal methods to evaluate microbial risks and their associated economic impacts have yet to be developed. Reinforcing this separation is the observation that the agencies usually responsible for carrying out these activities are different.

In this report, a risk analysis model based on typical slaughterhouse practices is linked with a decision model to evaluate the cost effectiveness of various combinations of pathogen reducing technologies. In a previous farm-to-table risk assessment of *Escherichia coli* O157:H7 for Canada, Cassin et al. (1998) identified slaughterhouses as representing a potential source for contamination of ground beef. Unfortunately, the scope of the model masks the contribution of individual slaughterhouse processes and, consequently, they were unable to model specific control options. Alternatively, Roberts et al. (1999) developed a quantitative risk assessment model that attempted to look more closely at the specific control options available in slaughterhouses. Jensen et al. (1998) evaluated improved food safety in the meat industry by comparing the costs and effectiveness of interventions using the mean pathogen reduction of technologies and combinations of technologies. This report uses the probabilistic risk assessment (PRA) model of Roberts et al. (1999) to evaluate the effectiveness of various technologies and to develop a preliminary cost effectiveness framework. It improves upon previous studies by explicitly incorporating probability distributions around slaughterhouse contamination and decontamination events, thus accounting for non-uniformity of their effectiveness. The framework outlined in this review can be used by the private sector in conjunction with the results obtained from the risk analysis to evaluate the cost-effectiveness trade-offs between technologies that individual plants might consider as they choose which pathogen reduction intervention strategy to adopt and thus compete effectively in the international marketplace.

Plants face both public and private incentives to produce safer food (Segerson 1999, Caswell & Mojduszka 1996, Van Ravenswaay & Bylenga 1991). McDowell et al. (1995: p 120) note "food safety managers are faced with the problem of assembling a 'portfolio' of mitigation techniques to obtain some desired level of safety (or maximizing safety for a given cost)." One strategy to manage food safety is exerting some prespecified level of effort at each step in production. An alternative strategy is identifying one or more "critical" steps, such as hide removal or post-slaughter carcass-pasteurization, and exerting extra effort there. The latter approach is the basis for the Hazard Analysis and Critical Control Point (HACCP) system that is now required for most food processing firms in the United States.

The private incentives are primarily litigation costs, loss of reputation, and the potential loss of the business itself. Deaths are more likely to result in a lawsuits, with the highest settlement reported being a Jack-in-the-Box payment of $15.6 million in 1995 for one child's brain damage in the 1993 *E. coli* O157:H7 outbreak associated with hamburger consumption (Buzby, Frenzen & Rasco, 2001).

However, Buzby and Frenzen (1999) found that "First, current legal incentives to produce safer food are weak, though slightly stronger in outbreak situations and in markets where food-borne illness can be more easily traced to individual firms. Far less than 0.01 percent of cases are litigated and even fewer are paid compensation. Second, even if potential plaintiffs can overcome the high information and transaction costs necessary to file lawsuits, monetary compensation provides only weak incentives to pursue litigation. Firms paid compensation in 56 percent of the 294 cases examined in this study and the median compensation was only $2,000 before legal fees."

Recent sales of plants producing ground beef (i.e., Hudson Foods) after the plants were found to have produced meat contaminated with *E. coli* O157:H7 indicate the high costs associated with a loss of reputation resulting from selling poor quality beef.[2] This threat of a loss in reputation suggests that plants have some incentive to adopt technologies that will reduce the likelihood of being identified as a source of poor quality beef (Klein & Leffler, 1981).

Public incentives historically have been prescriptive approaches to food safety mandating the use of certain equipment and facilities. Recently, the Food Safety Inspection Service (FSIS) has begun to use performance-based standards for pathogen control in meat and poultry products, namely testing for *Salmonella* and generic *E. coli*. The use of this performance standard allows plant operators to select the production processes and management systems that are most effective for them, given their market conditions and technical capacity (Bisaillon, Charlebois, Feltmate & Labbe, 1997, Powell, Ebel, Hogue & Schlowwer, 2001).

The public sector has also increased incentives by the establishment of FoodNet in 1995, greatly increasing the depth and accuracy of reporting for food-borne disease.[3] This new reporting system increases the probability of a food-borne illness being identified with a specific plant that produced the contaminated food product.

Whether or not a plant invests in existing food safety technologies or puts research effort into developing new technologies depends on the expected return on the investment. The private incentives for adopting pathogen-reducing technologies may also vary among plants selling to different markets and among plants of different size (Libecap, 1992). Plants with higher growth in product demand may be more likely to adopt pathogen-reducing technologies because their long-term profits are relatively higher.

The variation in size, age, and management of plants results in different adoption costs between plants for similar technologies. For instance, plants with higher cattle slaughter throughputs have lower equipment costs per head of cattle than do plants with lower throughputs. Plants with sufficiently high ground beef volumes may choose to irradiate their meat in-plant, while plants with lower volumes may either not irradiate or use a contract irradiator.

In this report, technological change is discussed with regard to pathogen reduction in a cattle slaughterhouse. Ground beef is an especially useful case, since fecal material and other contaminants may be ground into the final product. Because contaminants are distributed throughout the product, contaminants in the interior are less likely to be destroyed by cooking. Next, the use, effectiveness, and the degree to which different control technologies have penetrated the market, and factors affecting the adoption of these technologies are compared. A description of a cost-effectiveness framework for evaluating technology adoption follows, and an illustration for generic *E. coli* is provided. Under HACCP, meat and poultry firms are required to test for generic *E. coli* as an indicator of process control and a predictor

[2]In December 1998, Hudson Foods Inc., its plant manager, and a quality control official were indicted by a Federal grand jury and charged with conspiracy to provide false information to the U.S. Department of Agriculture in an attempt to hide contamination of millions of pounds of hamburger. Because of this incident, long-time rival, Tyson, bought Hudson Foods in a $632 million deal. Tyson is planning on phasing out the Hudson brand. James T. "Red" Hudson, former chairman of the board of Hudson Foods, stated that the contamination incident and the USDA reaction ". . . destroyed my company's good name, and led to the demise of Hudson Foods incorporated, as it existed at the time" (Belluck, 1998).

[3]Currently human illness data are collected at 9 sites around the country: California, Colorado, Connecticut, Georgia, Maryland, Minnesota, New York, Oregon, Tennessee. For details see http://www.cdc.gov/foodnet/

of the likelihood of contamination by pathogenic bacteria. The report concludes with a discussion of the institutional barriers and incomplete markets that affect the adoption and development of more effective technologies for pathogen reduction.

2. COST-EFFECTIVENESS OF PATHOGEN REDUCTION OPTIONS

The major steps in the cattle slaughtering process are shown in Figure 1. After cattle enter the slaughterhouse, they are stunned and killed. The carcass is generally hoisted to an overhead rail by a hind leg. During dehiding, the hooves are cut off, the hide removed, and the head removed; care must be taken to avoid the hide contaminating the sterile surface of the carcass. Next, knife trimming is required for pieces larger than one inch on carcasses, and steam vacuums (a hand-held instrument) can be used to remove visible pieces of dirt and other contaminants that can contain pathogens. Sometimes an additional decontamination step occurs here, such as a carcass water rinse. Next, the carcass is eviscerated (gastrointestinal tract is removed) and a chain saw is used to split the carcass in two along the backbone. The final decontamination is a combination of steam pasteurization in a cabinet for the sides of beef or a hot water wash, and perhaps an acid bath over the sides of beef. The sides of beef are chilled overnight. The next day, the sides of beef are graded and then cut into boxed beef and other market cuts in the fabrication step. The cuts of meat then enter the market where they are transported and may be ground or otherwise prepared, cooked at home or in a restaurant, and consumed.
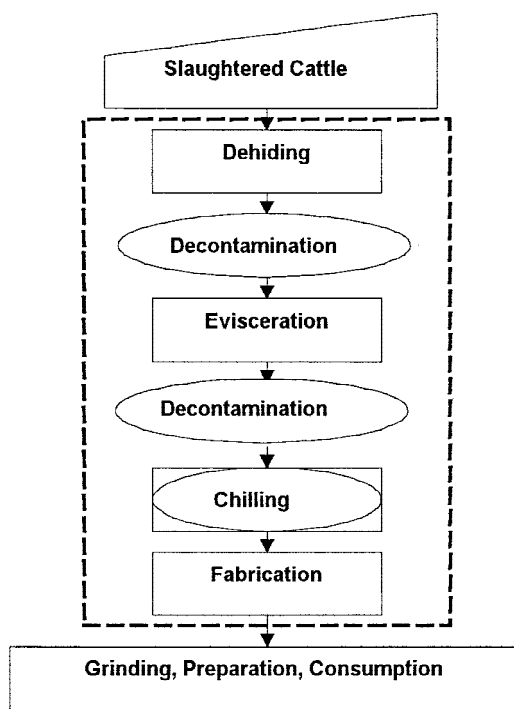

Figure 1   Steps in the ground beef production process (boxes represent contamination, ovals represent decontamination).

TABLE 1.   Available Technologies to Control Pathogens in Cattle Slaughterhouses

Technology	Plant size[a]	Cost Range (per head)	Effectiveness Range[b] (%)	Plants Using Technology (%)
Dehiding[c]	All	$0.01–$0.10	90–99	20
Steam vacuuming[d]	Large	$0.01–$0.02	50–80	100
Hot water/final carcass wash[d]	Small	$3.58	50–80	100
	Medium	$0.42	50–80	100
	Large	$0.28	50–80	50
Steam pasteurization[d]	Small	$3.58–$7.05	90–99	0
	Medium	$0.42–$0.78	90–99	0
	Large	$0.28–$0.46	90–99	50
Irradiation[e]	Small	$12.30	99–99.5	0
	Medium	$3.90	99–99.5	0
	Large	$3.82	99–99.5	0

[a]Large plants: 101–400 head/hr; Medium plants: 41–100 head/hr; Small plants: 0–40 head/hr.
[b]See Roberts, Malcolm, and Narrod (1999) for references on the effectiveness of the technologies as well as the text and Table 2 in this report for the distributions used in this analysis.
[c]Source: HACCP training costs are used as a rough proxy for the cost associated with training workers in improved dehiding methods. Estimate from L. Unnevehr (personal communication, 1999) on average of HACCP training for workers from four hog slaughter plants. From these estimates, adjustments are made for throughput in beef slaughter plants.
[d]From USDA estimates based on industry and manufacturer estimates.
[e]From estimates based on Morrison, Buzby and Lin (1997). Costs assume that whole carcasses are irradiated.

At any one step, meat can become contaminated by contact with its own hide, exposure to pathogens in the air or on equipment, cross contamination by workers, or contact with other contaminated carcasses. Efforts to prevent contamination are important at all steps, with careful removal of the hide being the most important in this model. Alternatively, pathogens can be killed or removed through the use of a variety of decontamination technologies. These include improving dehiding procedures (by requiring more frequent knife sterilization, reducing carcass handling, and limiting production of airborne particles, etc.), steam vacuum systems to remove visible spots of contamination, and procedures that treat the whole carcass at once (washes or steam pasteurization). Irradiation (in limited use for beef in the United States) is an additional technology that may prove to be very effective in eradicating pathogens.[4] These technologies differ in implementation and operating costs and effectiveness in eliminating pathogens.

To illustrate these differences, Table 1 shows the parameters associated with five alternative pathogen-reducing technologies for beef processing plants: improved dehiding, steam vacuuming, hot water carcass wash, steam pasteurization of carcasses, and irradiation of carcasses. Table 1 shows estimates of costs from vendors, effectiveness[5] as

[4]Irradiation was approved by the FDA in 1997 and on April 26, 1999, FSIS published its proposed rule on the irradiation of meat and meat products.

[5]Effectiveness is defined to be the range of reduction of generic *E. coli* from the carcass surface. Safety measures based on detecting the failure of process controls present an effective means of reducing the risk of human exposure to food-borne pathogens (Bisaillon et al., 1997; Pruett et al., 2002). Designing reliable and enforceable process control measures can be complicated by the fuzzy linkage between conditions in food processing establishments and public health outcomes, given the large number of variables in transportation, storage, distribution, preparations, and consumption (Powell et al., 2001).

determined by estimates derived from the literature under specific conditions, and the current status of adoption for each technology.

Economic theory suggests that plants will use the least-cost combination of technologies to achieve pathogen reduction that meets their market needs. To assess the relative value of these technologies, the net reduction obtained from applying combinations of improved technology options in a single large steer/heifer plant is computed. In the baseline case, the plant employs none of the improved technologies discussed above. Only three of the technology options listed in Table 1 are modeled: improved dehiding, steam pasteurization, and irradiation. From these three options, seven combinations are possible (each option used either singly or in combination). A second case provides an illustration of the effect of scale economies. A single technology is examined with different rates of adoption for irradiation assumed for large, medium, and small plants.[6]

To evaluate the overall effectiveness of reducing pathogens in the output of the plant, we use an earlier probabilistic risk assessment (PRA) model for generic *E. coli* (Roberts et al., 1999). Briefly, PRA quantitatively addresses the uncertainty and variability surrounding risk increasing and decreasing events. In this model, each step in the slaughterhouse either increases or decreases the pathogen load on a carcass by an amount drawn from a probability distribution. The probability distributions represent the range of contamination (in the case of contamination events) or the range of effectiveness (in the case of decontamination technologies). The output measure is the contamination level of generic *E. coli* in a quarter-pound hamburger patty.

By running the simulation model over a large number of iterations, a probability distribution is obtained for the final contamination level. The model is simulated for the baseline case, (i.e., no improved technologies are present) producing a cumulative distribution function (CDF) $F_0(x)$ that represents the percentage of outcomes with contamination level below desired threshold x. Including one or more pathogen reduction technology and simulating the modified PRA model results in a second CDF, $F_1(x)$, for comparison to the baseline. A priori expectations suggest that the CDF reflecting pathogen reduction should be shifted to the left of the baseline distribution. This shift reflects the degree to which pathogens are reduced in the final product.

The carcass contamination levels in this model generally have skewed distributions. Most beef carcasses have low levels of (or no) contamination, with a long tail representing a small number of heavily contaminated carcasses (Sofos et al., 1999). Estimating risk reduction by mean values masks changes to the tails of the risk distribution where the greatest risk lies.[7] An analysis that relies on mean values may: (1) misrepresent risk-cost tradeoffs, (2) lead firms to incorrectly target risk-reduction efforts, and (3) bias the intervention options that have the highest societal net benefits.

From a risk assessment standpoint, what is of interest is not the expected value of ground beef contamination but rather the frequency with which ground beef posing some level of risk occurs. Focus is, therefore, on the right-hand tail of the distribution, rather

---

[6]For this case, the effectiveness of different levels of irradiation adoption is evaluated. Three situations are considered that take into account that plants facing lower costs are likely to adopt technology before plants with higher costs. In situation L, 0% to 100% of large plants adopt irradiation, with no medium or small plants included. In situation M, 0% to 100% of medium plants adopt irradiation, with 100% of large plants adopting, and no small plant. In situation S, 0 to 100% of small plants adopt, with 100% of large and medium plants adopting.

[7]Note that if the individual risk elements were distributed symmetrically, the mean value would be a more accurate reflection of changes in the overall distribution of risk.

than the mean value. To evaluate the effectiveness of technology adoption strategies, a risk tolerance threshold is selected. The change of expected pathogen frequency above the threshold compared to the baseline model represents the effectiveness of the adoption strategy. This is expressed as:

$$\Delta P(\text{contamination above threshold}) = (F_1(\text{Threshold}) - F_0(\text{Threshold}))$$

The difference $F_1(x) - F_0(x)$ (where x is the desired threshold level) represents the increase or decrease in the probability that a hamburger patty is above the risk threshold that results from the process modification.

3. CATTLE SLAUGHTER PLANT MODEL

The slaughter plant is modeled as a simplified version of the process described in section 2. The four steps included are dehiding with pathogens introduced represented by the random variable (d), steam pasteurization (s), chilling (c), and fabrication (f). Monte Carlo simulation is used to compute the total contamination level present in a combo bin (X). At each iteration of the model, this value (expressed as $\log_{10}$ colony forming unit (CFU), that is the logarithm of the number of pathogens per square centimeter on the carcass surface) is determined by the sum of the four random variables defined above:

$$X = d + s + c + f$$

The average number of contaminants per quarter pound hamburger patty in CFU is given by:

$$N = \log_{10}((A * SA * (\%SA) * 10^X)/8{,}000)$$

where A is the number of animals contributing to a 2,000-pound combo bin of beef trim, SA is the surface area of the animal, %SA is the percentage of the surface area that ends up in the combo bin. There are 8,000 quarter-pound hamburger patties per combo bin. Most of the steer/heifer carcass becomes steaks and other cuts with only 20% ending up as trim going into hamburger or other ground products. For steer/heifers, an estimated 75% of the surface area (54,000 cm^2) contributes to ground products (McAloon, 1999, personal communication). Unlike steer/heifers, with cows only a few select cuts are left intact. Eighty percent of the cow carcass is destined for grinding (Duewer, 1999). On average, meat from 20 animals contributes to a combo bin in a steer/heifer plant.

3.1 Dehiding

The simulation begins by assigning a level of generic *E. coli* in $\log_{10}$ CFU/cm^2 reported by Gill (1999) on the hindquarters during hide removal. *E. coli* levels after the dehiding operation are modeled by a normal distribution. The mean value represents the carcass pathogen load at the end of the operation. Improvements in hide removal can result in a 2 $\log_{10}$ CFU/cm^2 reduction of generic *E. coli* deposited on the carcass surface (Gill, 1999).

3.2 Steam Pasteurization

The next step modeled is carcass decontamination before introduction to the chiller. Only steam pasteurization is considered in this model. Both steam pasteurization and hot water washes have highly variable applications, although plants with good process control can consistently achieve a 2 $\log_{10}$ CFU/cm^2 reduction of generic *E. coli*. (Gill, 1998).

3.3 Chilling

Following steam pasteurization, the carcass is stored in the chiller. Typically carcasses are chilled for 18–48 hours after slaughter. Studies of plants have found great variability in the ability to control the temperature in the chiller (Gill & Bryant, 1997). Maintaining a suitable temperature range is critical. Too high a temperature promotes pathogen growth, while lower temperatures tend to retard or reverse pathogen growth. Therefore, either contamination or decontamination may occur during chilling.

3.4 Fabrication

After chilling, the carcasses are fabricated into steaks, roasts, etc., and the remaining trim goes into ground beef. Gill's (1999) analysis of a group of plants suggests that plants that have good control of plant sanitation, temperature, and cross-contamination, often experience no increases in generic *E. coli*, while plants with poor process control may have increases up to 5 $\log_{10}$ CFU/cm^2.

The values used for the parameters of each component are given in Table 2. The values incorporate both variability and uncertainty present in each of the processes.

4. RESULTS

Figure 2 shows on the X-axis the cost per pound of each pathogen reduction option or combination in large steer/heifer plants. The Y-axis shows the percentage contamination reduction above the threshold that results from adopting the technology compared to the

TABLE 2.   Slaughter Plant Model Variables and Ranges

Process	Distribution[a]
Dehiding (d), typical	Log normal(2.27,0.5)
Dehiding (d), improved	Log normal(0.23,0.5)
Steam pasteurizing (s)[b]	Log normal(−1.5,0.5)
Chilling (c)[b]	Triangular(−1,1,0)
Fabrication (f)[b]	Log normal(0,0.5)[c]
Irradiation	Log normal(−3.0,0.5)

[a]Values given as $\log_{10}$ colony forming units (CFU) of generic *E. coli*/cm^2 of carcass surface. The Log Normal distribution parameters are mean and standard deviation for changes in $\log_{10}$ CFU/ of generic *E. coli*/cm^2. The Triangular distribution parameters are the minimum, maximum, and most likely values for changes in $\log_{10}$ CFU/ of generic *E. coli*/cm^2.
[b]Change in $\log_{10}$ CFU of generic *E. coli*/cm^2 on carcass surface.
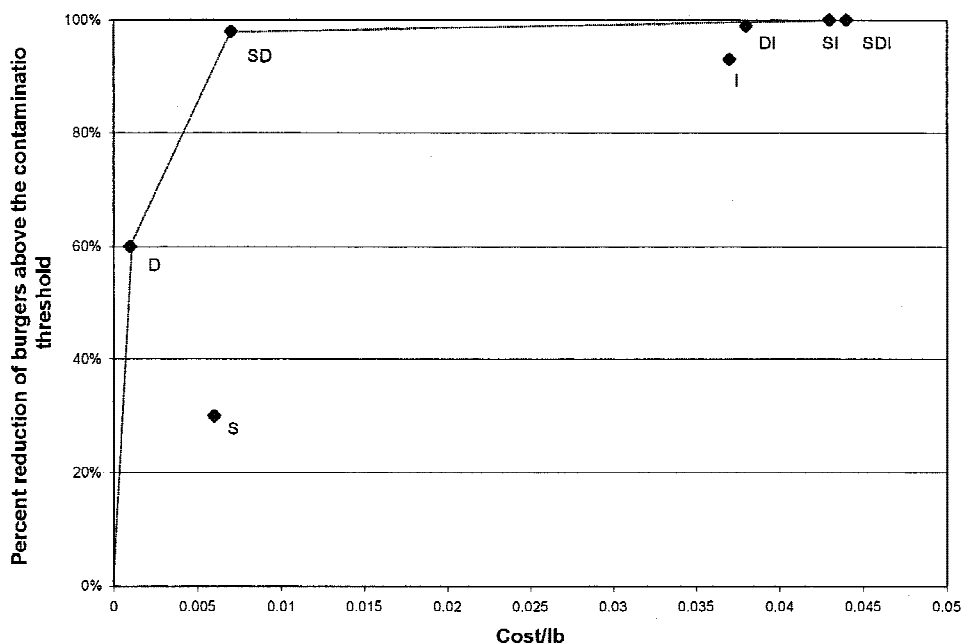[c]Only positive values allowed.

Figure 2   Trade-off curve for combinations of three technology adoption strategies in large steer/heifer plants (D = improved dehiding, S = steam pasteurization, I = irradiation).

baseline. The risk threshold selected is 10,000 generic *E. coli* per hamburger patty (Threshold = 10^4, or 4 logs)[8]. The non-dominated combinations of options are joined by a dotted line. This line represents the frontier with respect to the available options. Every choice containing improved dehiding lies on the frontier, as do some choices containing irradiation. Notice the synergy in combining steam pasteurization with improved dehiding procedures; the reduction in contamination is greater than the combination of the two individual processes. While irradiation provides additional protection, the marginal improvement over the improved dehiding plus steam pasteurization strategy comes at a significant cost increase. This analysis supports the multiple hurdle approach commonly used by the food industry for pathogen control in processing as well as developing new food products.

Certain technologies, such as irradiation and steam pasteurization, have economies of scale that favor large plants. For example, Morrison (1989) has estimated the economies of scale for meat irradiation and found that smaller plants using irradiation to decontaminate carcasses have significantly higher costs per pound. Results for the case of industry-wide irradiation adoption are shown in Figure 3. The marginal change in effectiveness per unit cost is much greater for situation L (large plants) than situation M (medium-sized plants), and likewise greater for situation M than situation S (small plants). This difference between plant sizes is less pronounced when the risk threshold is set higher at a level of 5 logs (100,000 generic *E. coli* per hamburger patty).

---

[8]Pathogen reduction is often quantified in terms of "log reduction.", e.g., a reduction in pathogen level from 10,000 to 1,000 (10^4 to 10^3) would be a one-log reduction. A reduction in pathogen level from 10,000 to 100 (10^4 to 10^2) would be a two-log reduction.
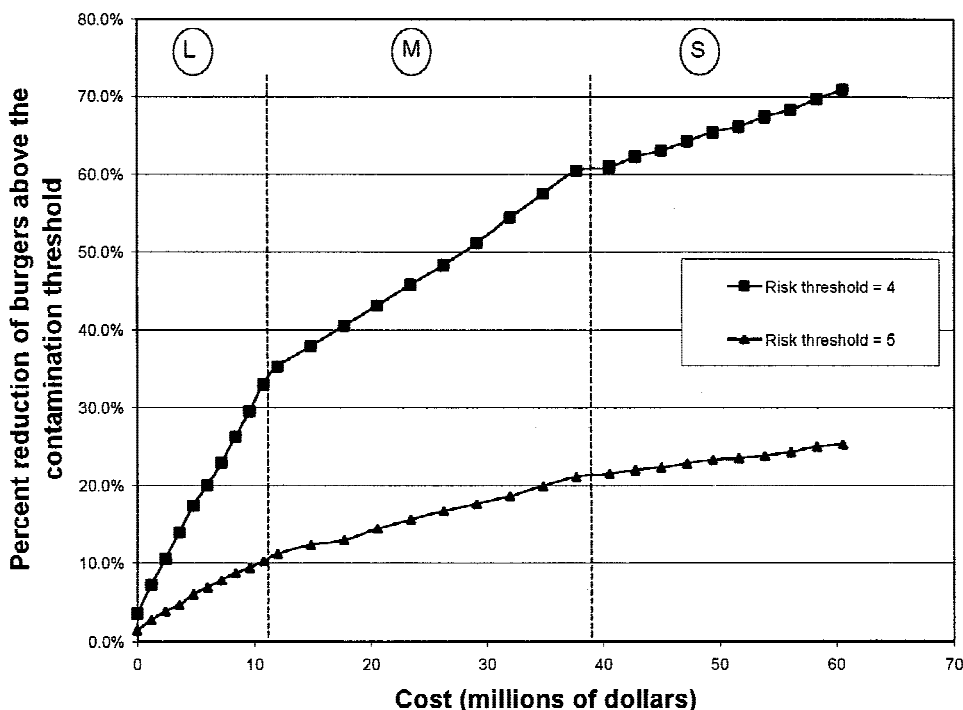
Figure 3   Effectiveness of irradiation under increasing adoption. Section L: range of costs and effectiveness for 0 to 100% of large plants; Section M: range of costs and effectiveness for 0 to 100% of medium plants and 100% of large plants; Section S: range of costs and effectiveness for 0 to 100% of small plants and 100% of large and medium plants.

Small plants may have a comparative advantage in careful hide removal if they have lower turnover and higher morale. Anecdotal evidence suggests that large plants have high turnover rates and thus a workforce with, on average, less experience than smaller plants. In addition, line speeds at the largest plants have increased to the point where 400 head per hour is common. The faster line speeds and greater crowding of carcasses in a plant can increase the probability of the air becoming contaminated during hide removal and increase the chances of carcass-to-carcass cross contamination. Both the less experienced workforce and faster line speeds in the largest plants suggest a greater chance for errors and increased odds of carcass contamination. In the model, the risk-reduction benefits for improved hide removal procedures (based on Gill's experience in beef slaughter plants (1999)) are a two-log reduction of contamination in the model, somewhat greater than steam pasteurization and only 1-log less than irradiation at much less cost.

To show how more realistic and logically complex processes can be modeled, a modification is made of the behavior of steam pasteurizing carcasses at the end of the slaughter line before they go into the chiller. In the baseline case, the effectiveness of the steam pasteurizer is modeled as a log normal distribution with a mean reduction of 1.5 $\log_{10}$ colony forming units (CFU) of generic *E. coli*/cm^2. The model is altered to explicitly acknowledge that the process may fail (the temperature may be insufficiently high or the time may not be long enough to kill pathogens). If a failure occurs, the steam pasteurization has no effect on the outcome. Failures are assumed to occur 25% of the time. The

remaining 75% of the time, steam pasteurization works as planned and achieves a 2-log reduction on the carcasses (a 0.5 log greater reduction than in the baseline case).

The output probability distribution in the baseline case now becomes bimodal (Fig. 4). The mean level of carcass contamination has not changed, yet there has been an increase in heavily contaminated carcasses with more than 5 logs of contamination/cm^2 of the carcass surface: an increase from 5.2% in the baseline case to 17.3%. A change of control strategy that has no effect on the mean contamination level led to a significant increase on risky outcomes above a threshold. Risk modeling approaches that rely on point estimates of risk or on mean values of distributions as the measure of risk are subject to overlooking critical characteristics of the distribution of risk. The public health impact of such changes to the risk distribution remains to be established by empirical studies.

Similarly, consider an alternative dehiding process that is slightly more effective on average but with a higher level of uncertainty (i.e., has a larger standard deviation). Under this new technology assumption, the mean value of contaminated hamburgers is slightly decreased, reflecting the greater effectiveness the alternative dehiding operation (Fig. 5). However, when threshold contamination levels are examined, the results show that there is *no* change in the contamination frequency above the threshold. Adopting the seemingly "improved" dehiding alternative would not result in an improved outcome, and would likely come at a higher cost.

5. DISCUSSION

This report has illustrated how technology evaluation can be linked with quantitative risk assessment models. The benefits of doing so are to enable food production enterprises to
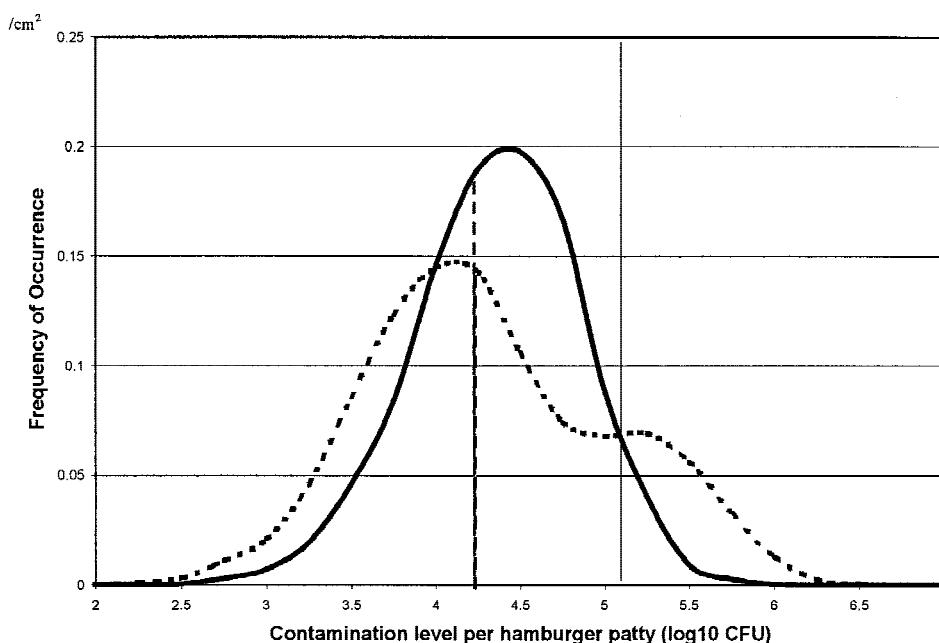

Figure 4   Change in outcome with modified technological assumption of steam pasteurization unit (Solid line: baseline; dashed line: modified steam pasteurizer).
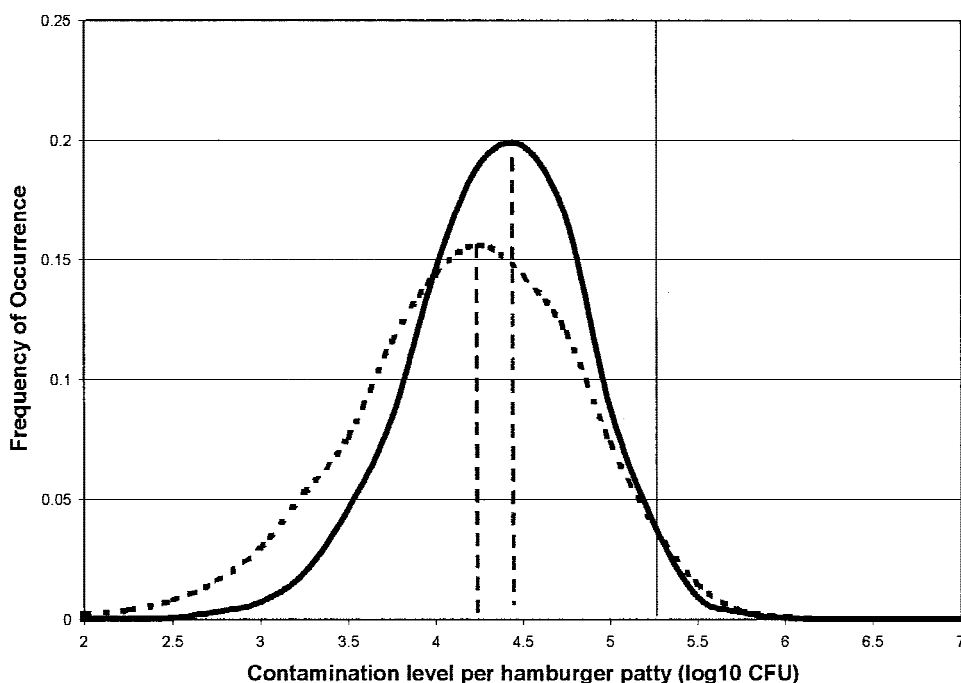
Figure 5   Change in outcome with modified technological assumption of dehiding process. (Solid line: baseline; dashed line: reduced mean and higher standard deviation in dehiding).

evaluate more clearly the trade-offs between costs of adopting food safety enhancing technologies and pathogen reduction.[9] Some choices are superior in terms of pathogen reduction, but more costly to certain plants based on their size of operation. For the case of irradiation, the analysis shows that the higher (less stringent) the risk threshold, the advantage of expensive, highly effective technologies is reduced. These technologies will greatly exceed the standard, resulting in higher costs than are necessary to achieve a less stringent standard. The PRA method also reveals complementarity between technologies that is unlikely to be discovered by other methods.

Unwillingness to invest in new technology to improve food safety by the private sector can be due to incomplete markets, which may be exacerbated by the failure of the market to properly signal consumer demand to producers (Hirshorn, Unnevehr, & Narrod, 1999). The existence of these strong market failures may also result in insufficient incentives for the private sector to adopt the technology once developed, and until these incentives are in place, companies or plants may not be willing to invest in food safety research (Fuglie, Narrod, & Neumeyer, 1999). Until then, private sector research will tend to be biased

---

[9]It should be recognized that we only evaluated a few technologies, whose efficacy may be improved over time through adaptive research by individual plants. (For example, increasing the time of exposure and temperature can increase steam pasteurization effectiveness.) Also, new scientific improvements in faster, cheaper tests for more pathogens increase the ability to ascribe liability to plants producing contaminated food. For example, the use of pulsed field gel electrophoresis (PFGE) as a DNA "fingerprinting" method to match strains of pathogens found in patients with that found in food may increase plants' concerns over liability in the future and affect the rate of adoption of pathogen reducing technologies.

toward those commodities, technologies, or research areas that have patentable technologies, large markets, or expanding demand. It can also be assumed that the technologies plants adopt will be biased in this direction.

To sell meat, plants must meet public regulatory requirements. Whether or not these regulations provide the proper level of economic incentives to compensate for possible market failures has been little researched. One ERS study suggests the public health protection benefits of increased control for meat and poultry are significantly greater than the costs of HACCP to the meat and poultry industry (Crutchfield et al., 1997).

Purvis and Outlaw's (1995) work on environmentally sound technologies found that the adoption of technologies to meet compliance obligations was fundamentally different from the adoption of production-enhancing technologies.[10] The reason for this is that "a large portion of the costs associated with the adoption of compliance technologies is the cost of capital investment (thus sunk costs) which are required" (Norris & Thurow, 1997, p. 6). Plants in part are reluctant to adopt such technologies because they do not necessarily receive immediate pay-offs for the adoption of the technology to offset investment costs (Norris & Thurow, 1997).

If the private and public incentives are insufficient, less than the socially optimal level of food safety will be produced. Firms will under-invest in R&D to develop new technologies and new management systems to control food-borne pathogens and be slow to adopt new technologies and management systems developed by others, despite their effectiveness in pathogen reduction. To support both the objectives of the firm and public health goals, analytical methods are needed that merge risk assessment and economic analysis so that rational decisions can be made about food safety technological development and adoption.

6. NOTE

Earlier versions of this paper were presented at the AAEA 1999 and the IAAE 2000, but the paper was not previously published.

REFERENCES

Belluck, P. (1998, December 17). U.S. indicts producer of contaminated beef. The New York Times, pp. A24.

Bisaillon, J.-R., Charlebois, R., Feltmate, T., & Labbe, Y. (1997). HACCP, Statistical Process Control applied to postmortem inspection and risk analysis in Canadian abattoirs. Dairy, Food, and Environmental Sanitation, 17, 150–155.

Buzby, J.C., & Frenzen, P. (1999). Food safety and product liability. Food Policy, 24, 637–651. Abstract on ERS website at: http://www.ers.usda.gov/briefing/IndustryFoodSafety/pdfs/liability.htm

Buzby, J.C., Frenzen, P.D., & Rasco, B.A. (2001). Product liability and microbial foodborne illness. Agricultural Economic Report, USDA/ERS, AER 799. Available on the ERS website at: http://www.ers.usda.gov/Publications/aer799/aer799.pdf

Cassin, M., Lammerding, A., Todd, E., Ross, W., & McColl S. (1998). Quantitative risk assessment of E. coli O157:H7 in ground beef hamburgers. International Journal of Food Microbiology, 41, 21–44.

[10]This argument has been used for environmental technologies and environmental compliance, but the same argument could be used for food safety technologies.

Caswell, J.A., & Mojduszka, E.M. (1996). Using information labeling to influence the market for quality in food products. American Journal of Agricultural Economics, 78, 1248–1253.

Crutchfield, S.R., Buzby, J.C., Roberts, T., Ollinger, M., & Jordan Lin, C.-T. (1997). An economic assessment if food safety regulations: The new approach to meat and poultry inspection. Food and Consumer Economics Division, USDA/ERS, AER 755. Available on the ERS website at: http://www.ers.usda.gov/briefing/FoodSafetyPolicy/features.htm

Duewer, L. (1999). Red Meat Book. USDA/ERS. Available on the ERS website at: http://www.ers.usda.gov/data/sdp/view.asp?f=livestock/94006/

Fuglie, K., Narrod, C., & Neumeyer, C. (2000). Public and private investment in animal research. In K. Fuglie & D. Schimmelpfennig (Eds.), Public-private collaboration in agricultural research: New institutional arrangements and economic implications (pp. 117–151). Ames, IA: Iowa State University Press.

Gill, C.O. (1998). Apparatus for pasteurizing red meat carcasses. Technical Bulletin 1998–5E. Lacombe, Alberta: Agriculture and Agri-Food Canada.

Gill, C.O. (1999). HACCP: By guesswork or by the numbers? Food Quality, 6, 28–32.

Gill, C.O., & Bryant, J. (1997). Assessment of the hygienic performances of two beef carcass cooling processes from product temperature history data or enumeration of bacteria on carcass surfaces. Food Microbiology, 14, 593–602.

Hirshorn, N., Unnevehr, L., & Narrod, C. (1999). Animal and plant health and food safety: An issue paper concerning future World Bank involvement, white paper prepared for the World Bank.

Jensen, H.H., Unnevehr, L.J., & Gomez, M.I. (1998). The costs of improving food safety in the meat sector. Journal of Agricultural and Applied Economics, 30, 83–94.

Klein, B., & Leffler, K. (1981). The role of market forces in assuring contractual performance. Journal of Political Economy, 89, 615–631.

Libecap, G. (1992). The rise of the Chicago packers and the origins of meat inspection and antitrust. Economic Inquiry, 30, 242–262.

McDowell, R., Kaplan, S., Ahl, A., & Roberts, T. (1995). Managing risks from foodborne microbial hazards. In T. Roberts, H. Jensen, & L. Unnevehr (Eds.), Tracking foodborne pathogens from farm to table (pp. 117–124) USDA/ERS, MP-1532. Available on the ERS website at: http://www.ers.usda.gov/publications/MP1532/mp1532.pdf

Morrison, R.M. (1989). An economic analysis of electron accelerators and cobalt-60 for irradiating food. USDA Economic Research Service, Technical bulletin 1762.

Morrison, R., Buzby, J., & Lin C.-T.J. (1997). Irradiating ground beef to enhance food safety. FoodReview, 20, 33–37. Available on ERS website at: http://www.ers.usda.gov/publications/foodreview/jan1997/jan97e.pdf

Norris, P., & Thurow, A. (1997). Environmental policy and technology adoption in animal agriculture. Department of Ag. Econ. Michigan State University, AEC Staff paper 97–28.

Powell, M.R., Ebel, E.D., Hogue, A.T., & Schlowwer, W.D. (2001). The promise and challenge of food safety performance standards. Dairy, Food, and Environmental Sanitation, 21, 582–590.

Pruett, W.P., Jr., Biela, T., Lattuada, C.P., Mrozinski, P.M., Barbour, M., Flowers, R.S., Osborne, W., Reagan, J.O., Theno, D., Cook, V., McNamara, A.M., & Rose, B. (2002). Incidence of *Escherichia coli* O157:H7 in frozen beef patties produced over an 8-hour shift. Journal of Food Protection, 65, 1363–1370.

Purvis, A., & Outlaw, J. (1995). What do we know about technological innovation to achieve environmental compliance: Policy issues for an industrializing animal agricultural sector. American Journal of Agricultural Economics, 77, 1237–1243.

Roberts, T., Malcolm, S., & Narrod, C. (1999). Probabilistic risk assessment and slaughterhouse practices: Modeling contamination process control in beef destined for hamburger. In M. Modarres (Ed.), PSA '99: Proceedings of the international topical meeting on probabilistic safety assessment (pp. 809–815), LaGrange Park, IL: American Nuclear Society, Inc. Available on ERS website at: http://www.ers.usda.gov/briefing/IndustryFoodSafety/pdfs/psa9.pdf

Segerson, K. (1999). Mandatory versus voluntary approaches to food safety. Agribusiness, 15, 53–70.

Sofos, J., Kochevar, S.L., Bellinger, G.R., Buege, D.R., Hancock, D.D., Ingraham, S.C., et al. (1999). Sources and extent of microbiological contamination of beef carcasses in seven United States slaughtering plants. Journal of Food Protection, 62, 140–145.

Van Ravenswaay, E.O., & Bylenga, S.A. (1991). Enforcing food safety standards: A case study of antibiotic and sulfa residues in veal. Journal of Agribusiness, 9, 39–53.

Scott A. Malcolm *is Assistant Professor in the Food and Resource Economics Department and the Operations Research Program at the University Delaware. He received a Ph.D. in Systems Engineering from the University of Pennsylvania in 1996. His research interests focus on the application of quantitative methods to evaluate investment/choice decisions under risk and uncertainty when environmental factors are present. He worked on the USDA's E. coli O157:H7 risk assessment team. He can be reached at Malcolm@udel.edu or (302) 831–1316.*

Clare A. Narrod *is a livestock economist at the Office of Risk Assessment and Cost-Benefit Analysis at USDA. She earned her Ph.D. in Energy Management and Policy from the University of Pennsylvania in 1997. She was an AAAS Risk Fellow from 1998 to 2000, and recently completed 2 years working on issues related to environmental resources and livestock production at FAO. She was a member of USDA's risk assessment team for E. coli O157:H7 in ground beef. She can be reached at cnarrod@oce.usda.gov or (202) 690–5415.*

Tanya Roberts *is an economist at the Economic Research Service in the Diet, Safety and Health Economics Branch, where she served as the economics editor for food safety on the new ERS website and coordinated the development of the five briefing rooms on the economics of food safety. She earned her Ph.D. in Economics from the University of Washington in Seattle in 1979. Her current research interests include analysis of food safety policies, integrating risk assessment into benefit/cost analyses of control options, and private incentives to develop new pathogen control technologies and management systems. Tanya pioneered ERS' estimates of the social costs of bacterial and parasitic food-borne diseases, and testified before Congress in 1987. She served on the Board of the regional research committee, NE-165 "Public Policies, Private Strategies, and Food System Performance," for over a decade and was on the organizing committee for most of their food safety conferences. Recently, Dr. Roberts was a member of USDA's risk assessment team for E. coli O157:H7 in ground beef. She can be reached at tanyar@ers.usda.gov or 202–694–5464.*

Michael Ollinger *is an economist at the Economic Research Service in the Diet, Safety and Health Economics Branch, working in the areas of food safety and meat and poultry industry structural changes. He received a Ph.D. from Washington University in St. Louis in 1991. His current research interests are food safety innovation and regulatory cost requirements in the meat and poultry industry and food industry mergers and acquisitions. He can be reached at Ollinger@ers.usda.gov or (202) 694–5454.*